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FINAL REPORT

Contract No. ARDS-434, Amend. 5

Project No. 430-202-01N

INSTITUTE SPECIAL REPORT

PHOTOMETRIC DETECTION CONTRAST OF AIRPORT LIGHTING IN DECREASING VISIBILITY

AUGUST 1966

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Systems Research & Development Service

THE INSTITUTE OF TRANSPORTATION
AND TRAFFIC ENGINEERING
UNIVERSITY OF CALIFORNIA

FINAL REPORT

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PHOTOMETRIC DETECTION CONTRAST OF AIRPORT LIGHTING IN DECREASING VISIBILITY

August 1966

Prepared by
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This report has been prepared by the Institute of Transportation and Traffic Engineering, University of California, for the Systems Research and Development Service, Federal Aviation Agency, under Contract No. FAA ARDS-434. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification or regulation.

Institute of Transportation and Traffic Engineering
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ABSTRACT

A photometric method is described for determining the visibility of airport runway lights under various conditions of visual range and background brightness. The method is based on measurement of a defined quantity, C_d, called photometer detection contrast, and depends on the correlation of this quantity with subjective visibility. Use of the photometric method is illustrated by tests conducted in the FAA Fog Chamber. Values of C_d were calculated from luminance scans of runway lights in daytime and nighttime visual ranges of 1600, 1200, and 800 ft. Maximum visibility distances for the lights were then determined by assuming a trial value of .06 as the minimum usable C_d for subjective visibility under the various fog conditions. An automatic scanner mechanism used with a telephotometer for the efficient acquisition of the luminance data is also described.

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INTRODUCTION

Amendment 5 to contract ARDS-434 called for tests to determine at what points approaching zero visibility the various elements of a modern airport lighting system begin to deteriorate, and also to determine the effectiveness of runway centerline lighting in providing rollout guidance in all-weather operations.

This report deals with the first part of the assignment, namely, a study of how the effectiveness of the runway lighting system is degraded under conditions of decreasing visibility. The second part of the assignment, concerning rollout guidance of the centerline lights, will be carried out as part of a later study covered by a subsequent contract amendment, since the later amendment requires that the same type of information be derived but in greater detail.

The lighting system used in these tests had the following configuration and light intensities:

System Component	Peak Intensity*
Approach lights (modified system**)	20,000 cp day, 4000 cp night
Runway edge lights	20,000 cp day, 4000 cp night
Touchdown zone lights (100-ft spacing)	7500 cp day and night
Centerline lights (25-ft spacing)	2000 cp day and night
Threshold lights	Same as approach lights but with aviation green filters

Amendment 5 specified that pilot observers be used for the evaluation tests. However, because this method has in the past proved to be quite time-consuming, it was decided in this instance to try a different method based on a specially developed photometric technique. In this method, a telephotometer is used to measure the luminance of the lights in the system under the various test conditions, and the "photometer detection contrast", as defined later in the report, is calculated from the luminance data. Using the minimum value of contrast required for a light to be visible to a human observer, it is then possible to determine how many light elements in each component of the system would be seen by the observer under a given set of conditions.

In the tests reported here, luminance measurements were made in both daytime and nighttime fog with visual ranges of 1600, 1200, and 800 ft. Under each of these conditions, data were obtained with the telephotometer stationed at the following points on the glide path: 2000 ft, 1500 ft, 1000 ft, and 500 ft in front of the runway threshold, as well as at the threshold.

Although the data obtained in these tests are not sufficiently definitive to make the determinations specifically called for by the contract assignment, they do illustrate that the photometric technique herein described can be applied toward that end once the proper correlations between subjective and photometer detection contrasts have been established. It is proposed that the work necessary to establish such correlations be included under a subsequent phase of the contract.

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* Equivalent full-scale values.

**See: Finch, D. M., R. Horonjeff, and H. G. Paula, Evaluation of Runway Lighting Systems for Effectiveness in Dense Fog, Final Report, FAA Contract ARDS-434, Report No. RD-65-58, January 1966, p. 56.

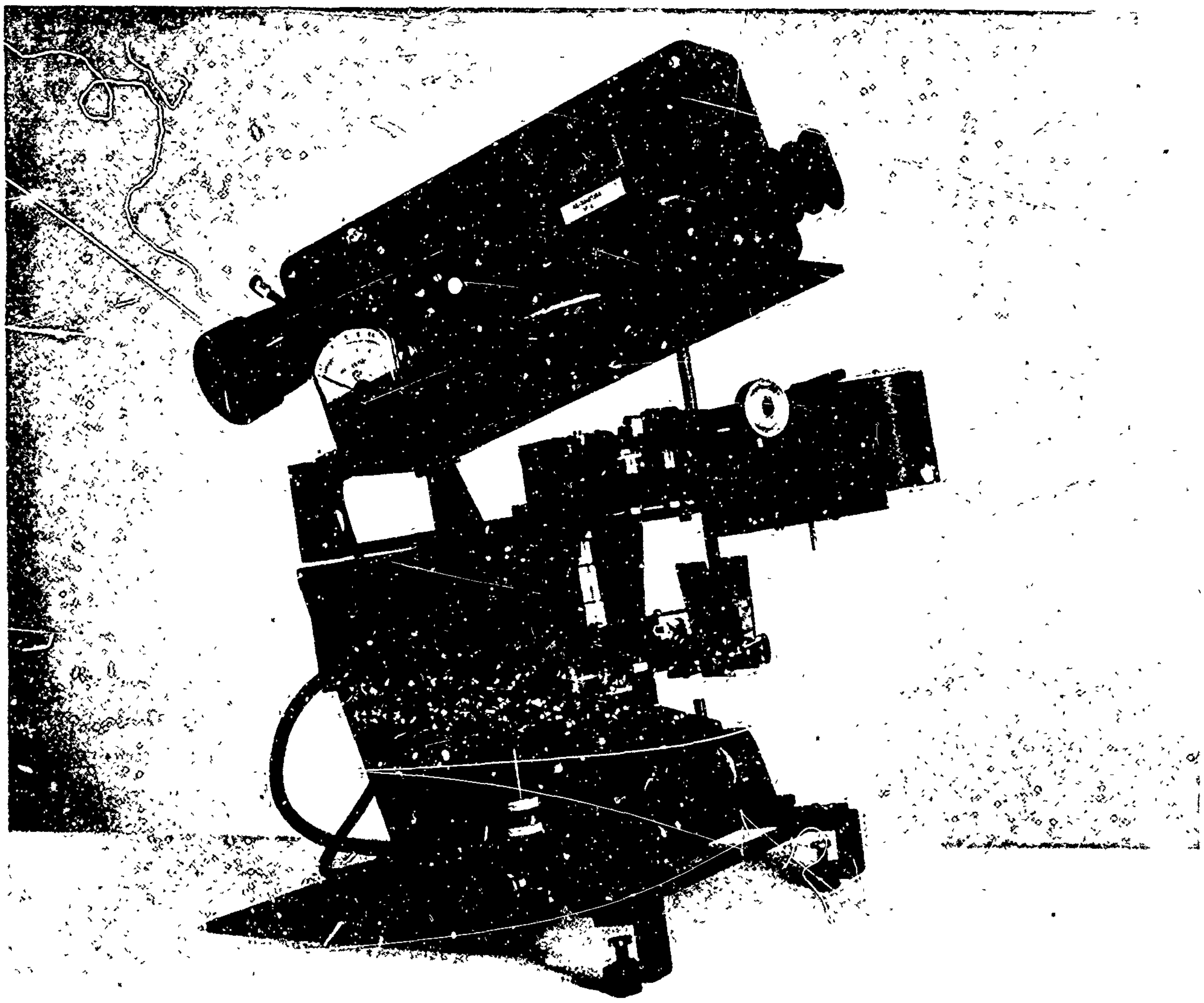

Fig. 1. Telephotometer mounted on automatic scanner assembly.

METHODS AND PROCEDURES

Test Facility

The Fog Chamber, in which these tests were performed, is a long, narrow building whose height decreases along a $2\frac{1}{2}°$ slope from one end to about the middle, and then stays constant for the remainder of its length. The roof and upper portion of the sides are covered with translucent corrugated panels to admit light for daytime fog studies. Light fixtures installed in the floor of this building are controlled to provide various approach and in-runway lighting patterns. A cockpit cabin, suspended from a tramway carriage that runs on overhead rails down the length of the building, allows observers to view the lights while traveling along a simulated landing path.

All tests in the Fog Chamber reported herein were conducted at 1/10 scale. This means that all linear dimensions are reduced to 1/10 of their full-scale equivalents, while other parameters such as light intensity and fog density are reduced by appropriate scale factors so that the visual scene in the Fog Chamber appears the same to an observer as does the full-scale equivalent. All dimensions given in the report in connection with the Fog Chamber tests are corresponding full-scale values.

Fog is generated inside the building by a compressed-air and water system which forces a fine spray out of nozzles located at various points along the walls. This system can be controlled to maintain a fog of the required density throughout the tests.

Visibility during the tests is determined by having observers, stationed along one edge of the runway, look at 10,000 cp (equivalent full-scale intensity) light sources placed on 200-ft centers along the opposite edge. When all observers report seeing the same specified number of lights, the visibility is known to be at the required level. The visiblity thus determined is here called "Visual Range" as distinguished from the term "Runway Visual Range" (RVR), which is generally associated in the United States with visibility values obtained from transmissometer readings.

The method for determining Visual Range is discussed further in a previous report, which also describes the test facility in greater detail.*

Test Apparatus

The apparatus used in these tests for making luminance measurements consisted of a Spectra-Pritchard telephotometer mounted on the turntable of a scanner assembly as shown in Fig. 1. The telephotometer uses apertures of various size and measures the average light flux at the photoelectric receiver within the specified acceptance angle of its aperture.**

The scanner assembly, developed especially for this project, includes a drive mechanism that is capable of both rotating the turntable horizontally and moving it through a vertical angle. It also includes controls by means of which the apparatus can be programmed to provide automatically a continuous luminance scan covering a longitudinal ground segment of any width and length.

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* Finch, et al., op. cit., pp. 9-12.

**The quantity thus measured is known as photometric brightness or luminance. For a theoretical discussion of lens-type photometers with fixed apertures see D. E. Spencer, "Out-of-Focus Photometry," Journal of the Optical Society of America, Vol. 55, No. 4 (April 1965), pp. 396-403.

Fig. 2. Photometric equipment set up in cockpit cabin for tests.

In addition to the continuous-scan mode, the apparatus can also be set to provide single transverse sweeps at fixed distances ahead. The electrical output of the telephotometer is fed to a strip-chart recorder which provides a trace of the luminance measured during the scan. Calibration of the apparatus is accomplished by means of a Spectra Luminance Standard.

With the scanner set for automatic operation, the telephotometer begins its continuous scan by sweeping across the ground segment at the nearest point from one edge to the other. When the turntable reaches the preset limit of its horizontal travel, the vertical angle of the telephotometer is changed by a predetermined amount. At the same time, the horizontal drive is reversed so that the telephotometer scans the next transverse section of the ground segment in the opposite direction. This process continues, with the telephotometer sweeping back and forth across the longitudinal strip of area until the section at the farthest point of the scan has been covered.

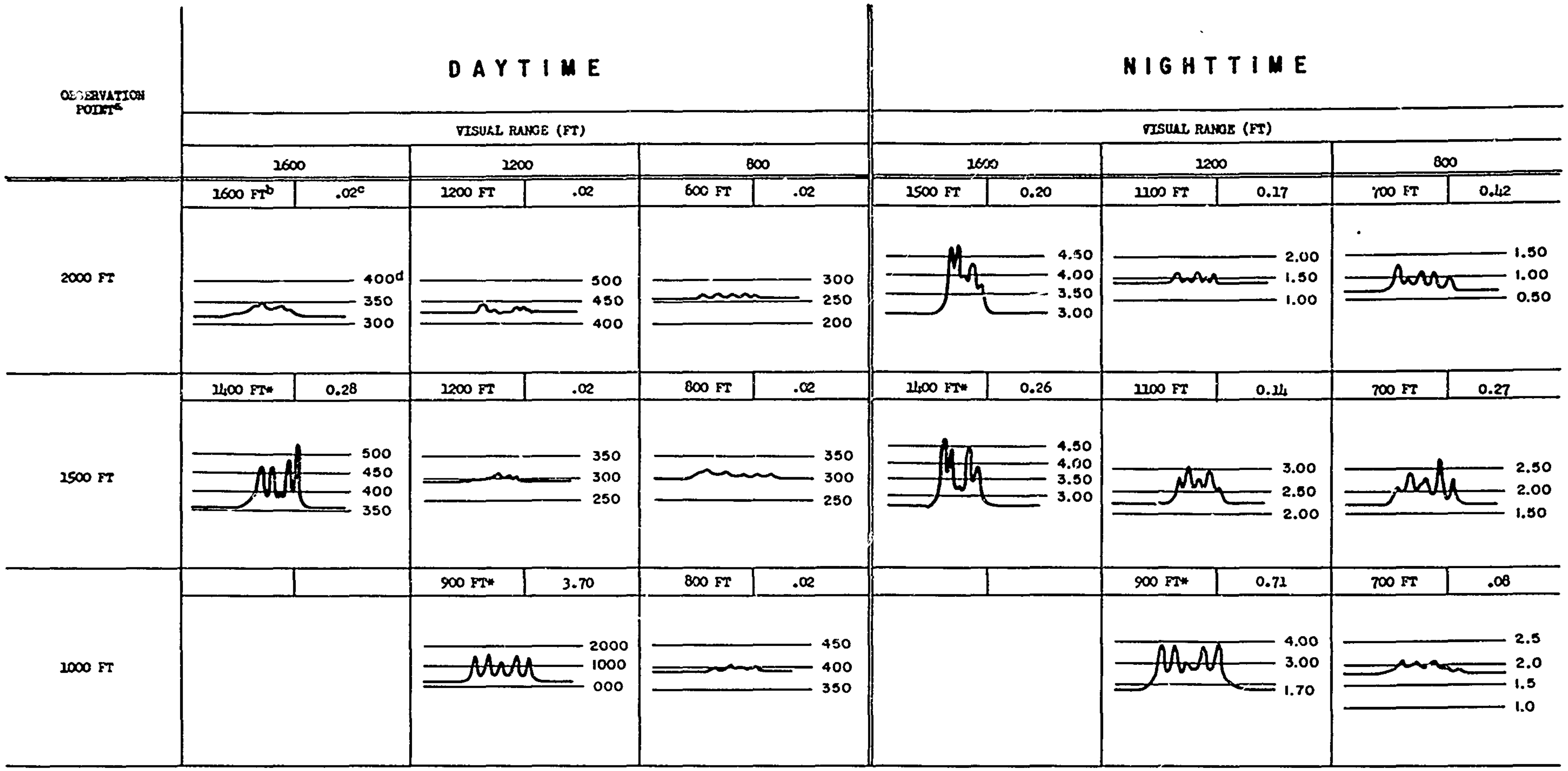
The scanner has provisions for adjusting the scanning rate as well as for setting the horizontal and vertical angular limits of travel. Furthermore, the mechanism can be set to reduce the horizontal sweep angle by the required amounts during operation so that the telephotometer covers transverse sections of approximately equal length as it moves from the nearest to the farthest points of the longitudinal segment being scanned. This helps to conserve both scanning time and recording-chart paper. The vertical angle indexed during operation is likewise automatically reduced so that the optical axis of the telephotometer advances by approximately equal distance increments along the ground from the nearest to the farthest points scanned.

Test Procedures

With the apparatus set up in the cockpit cabin of the tramway system as shown in Fig. 2, luminance measurements were made in both daytime and nighttime fogs with visual ranges of 800, 1200, and 1600 ft. In each case, the cockpit was stationed on the glide path at distances of 2000 ft, 1500 ft, 1000 ft, and 500 ft in front of the runway threshold, as well as at the threshold. At each of these five positions, the telephotometer was aimed at the farthest perceptible light element of each component of the lighting system in view and the scanner was set to provide a single sweep of the ground segment at each of these points. A corresponding luminance curve was thus obtained for each such light element scanned (see Figs. 3 through 7).

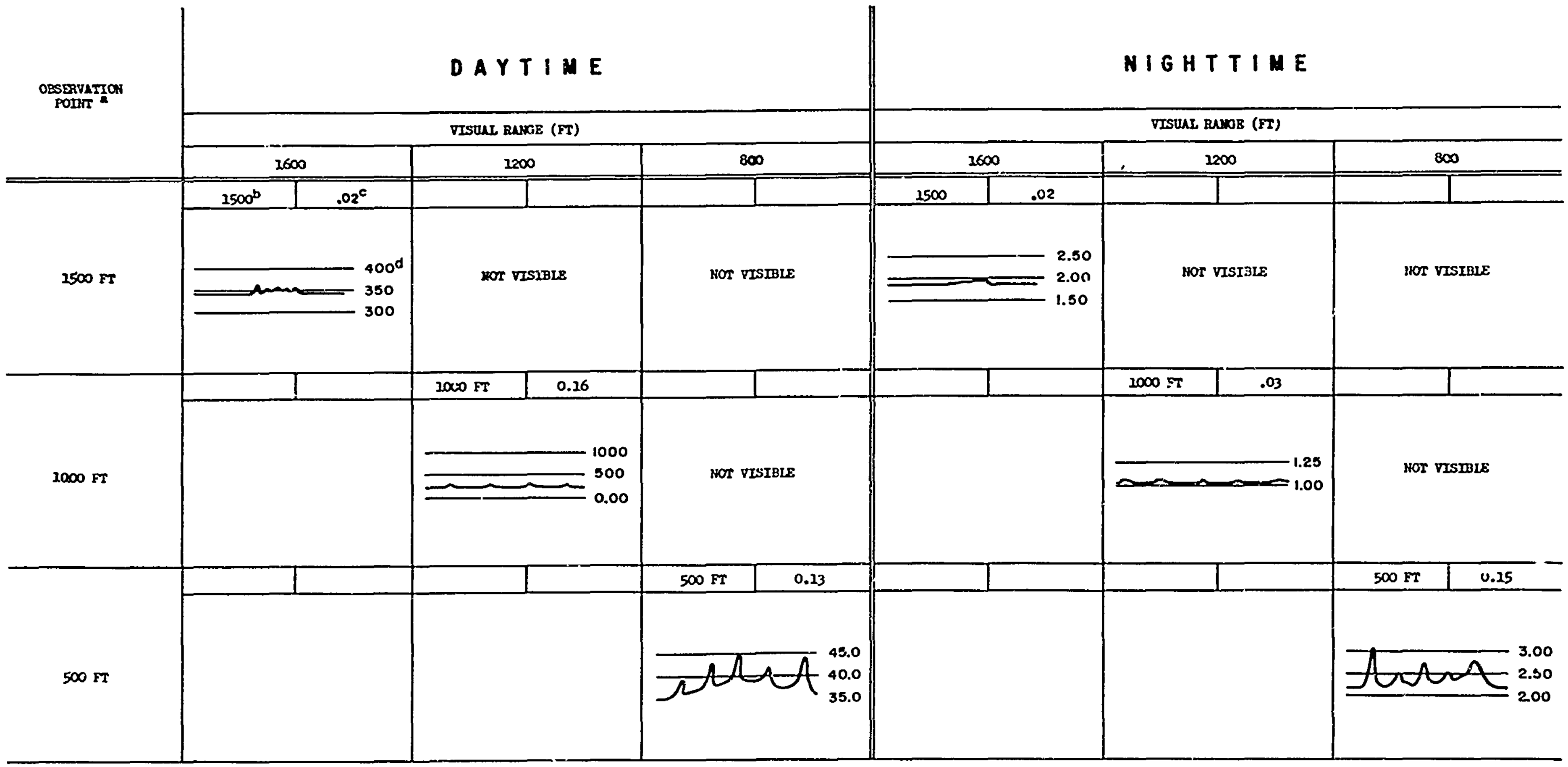
As previously discussed, the size of the telephotometer aperture was changed as required to keep the projected area within the field of the photometer as nearly the same for all scanning distances as possible. Thus, a 2' aperture was used with the visual range at 1600 ft, a 4' aperture at 1200 ft, and a 6' aperture at 800 ft.

In addition to the single-scan measurements described above, a continuous scan of the runway lighting system was made from a distance of 1000 ft in front of the threshold in a visual range of 1200 ft both during the day and at night. For these scans, the apparatus was set to operate automatically as previously described. A photometer aperture of 4' was used and the scanner was adjusted to operate with a vertical angular indexing equal to half of the aperture size, or 2'. Scanning began at the nearest portion of the runway in view (as determined by the cockpit cutoff angle of 15°) and continued until the light sources scanned were too distant to produce a measurable response from the photometer. In this way, continuous luminance traces were obtained for all components in the runway lighting system from the nearest to the farthest points covered. Fig. 8, showing the complete luminance trace for one approach-light barrette, represents a typical example of a continuous-scan recording. Figs. 9 and 10 show what may be a useful way of depicting the photometric data. These diagrams may be thought of as luminance maps of the runway lighting system in day and night respectively; they were constructed from the corresponding continuous-scan recordings by taking successive sections of the traces and placing them in the proper relative positions.



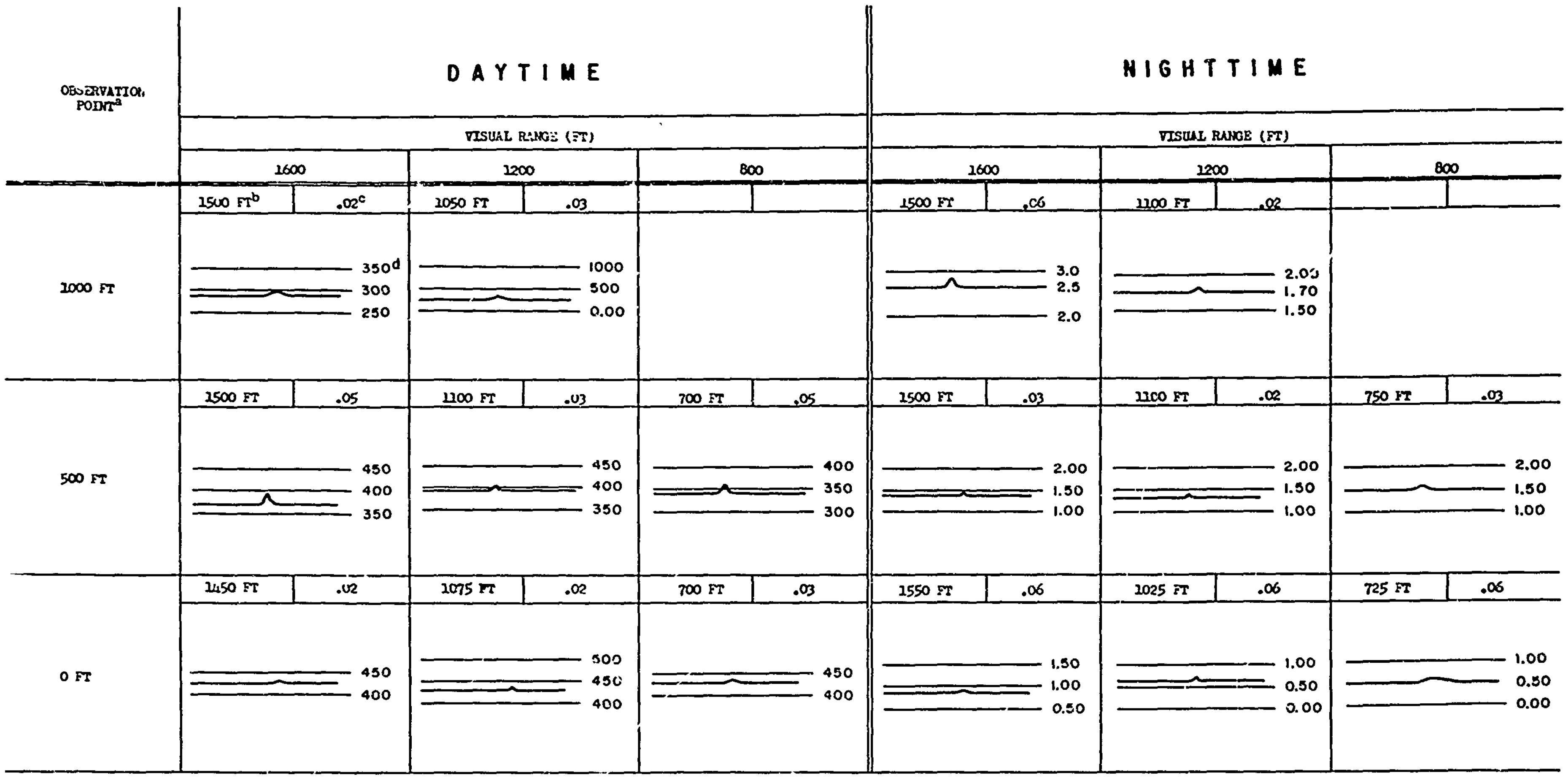
a. Distance before runway threshold
b. Distance from observation point to light source
c. Photometer detection contrast, C_d
d. Luminance in footlamberts
* Distance from observation point to last approach light barrette before runway threshold

Fig. 3. Single-scan luminance curves and photometer detection contrasts for farthest perceptible approach lights.



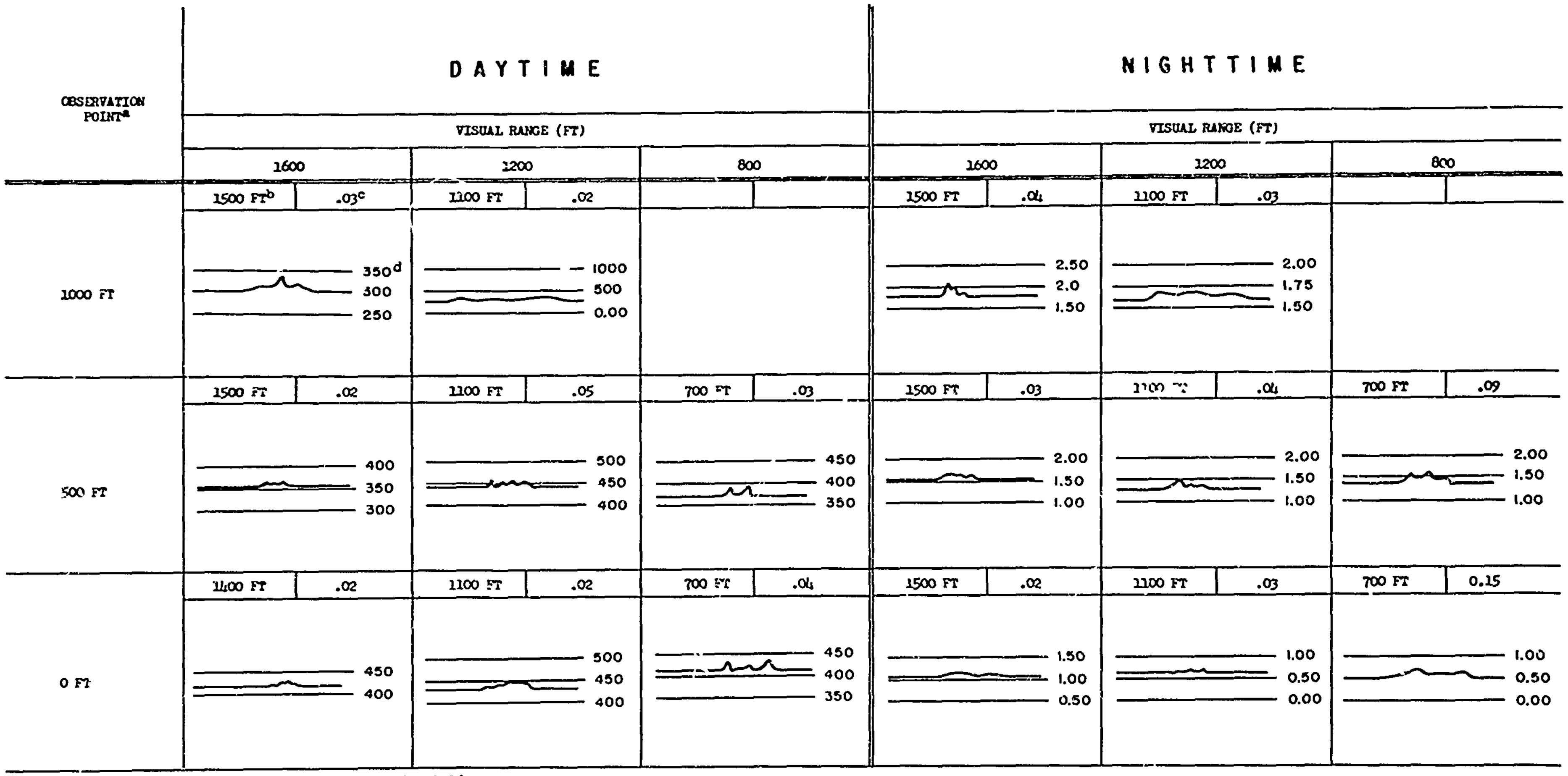
a. Distance before runway threshold
b. Distance from observation point to light source
c. Photometer detection contrast, C_d
d. Luminance in footlamberts

Fig. 4. Single-scan luminance curves and photometer detection contrasts for runway threshold lights.



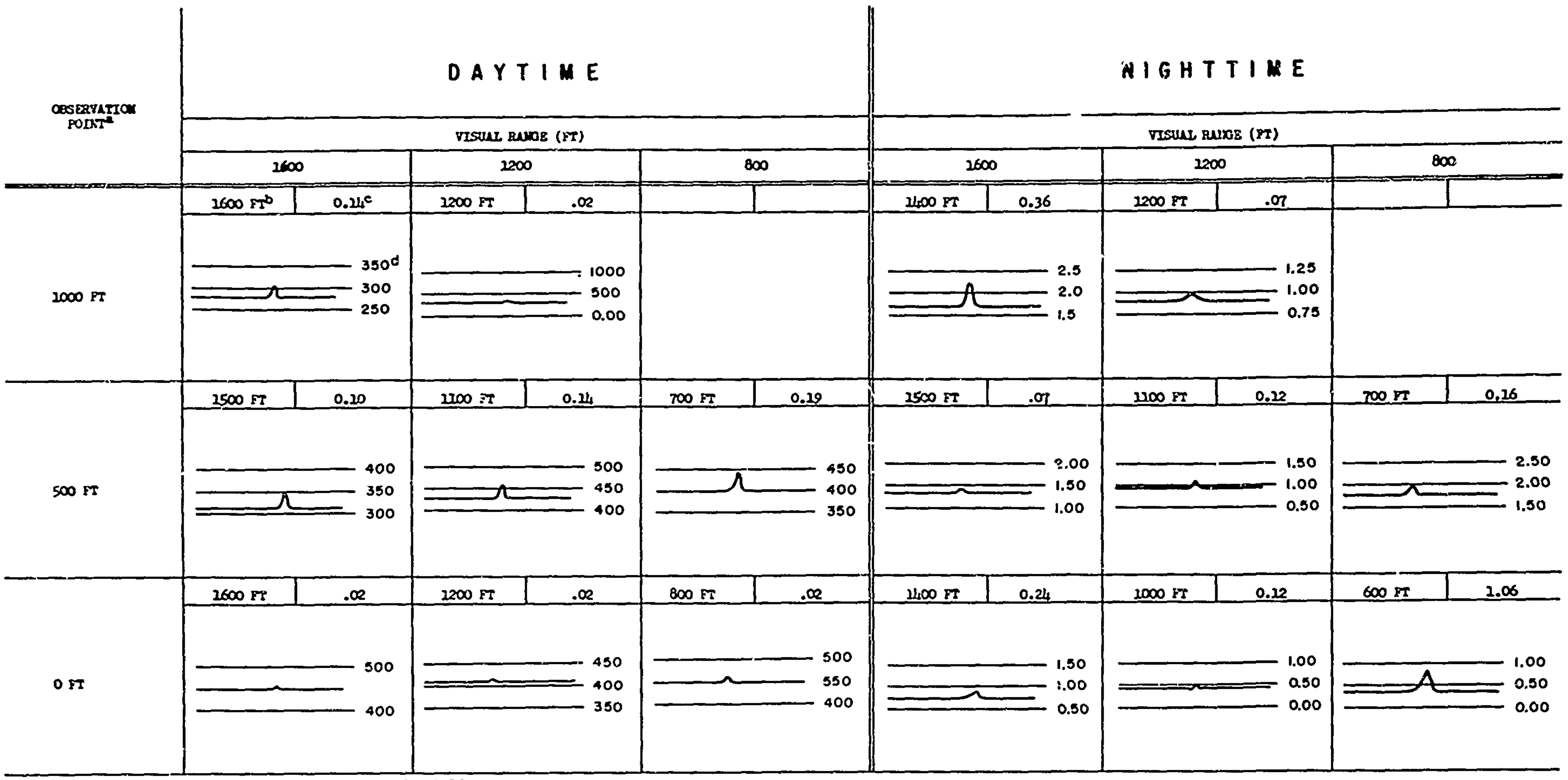
a. Distance before runway threshold
b. Distance from observation point to light source
c. Photometer detection contrast, C_d
d. Luminance in footlamberts

Fig. 5. Single-scan luminance curves and photometer detection contrasts for farthest perceptible centerline lights.



a. Distance before runway threshold
b. Distance from observation point to light source
c. Photometer detection contrast, C_d
d. Luminance in footlamberts

Fig. 6. Single-scan luminance curves and photometer detection contrasts for farthest perceptible touchdown-zone lights.



a. Distance before runway threshold
b. Distance from observation point to light source
c. Photometer detection contrast, C_d
d. Luminance in footlamberts

Fig. 7. Single-scan luminance curves and photometer detection contrasts for farthest perceptible edge lights.

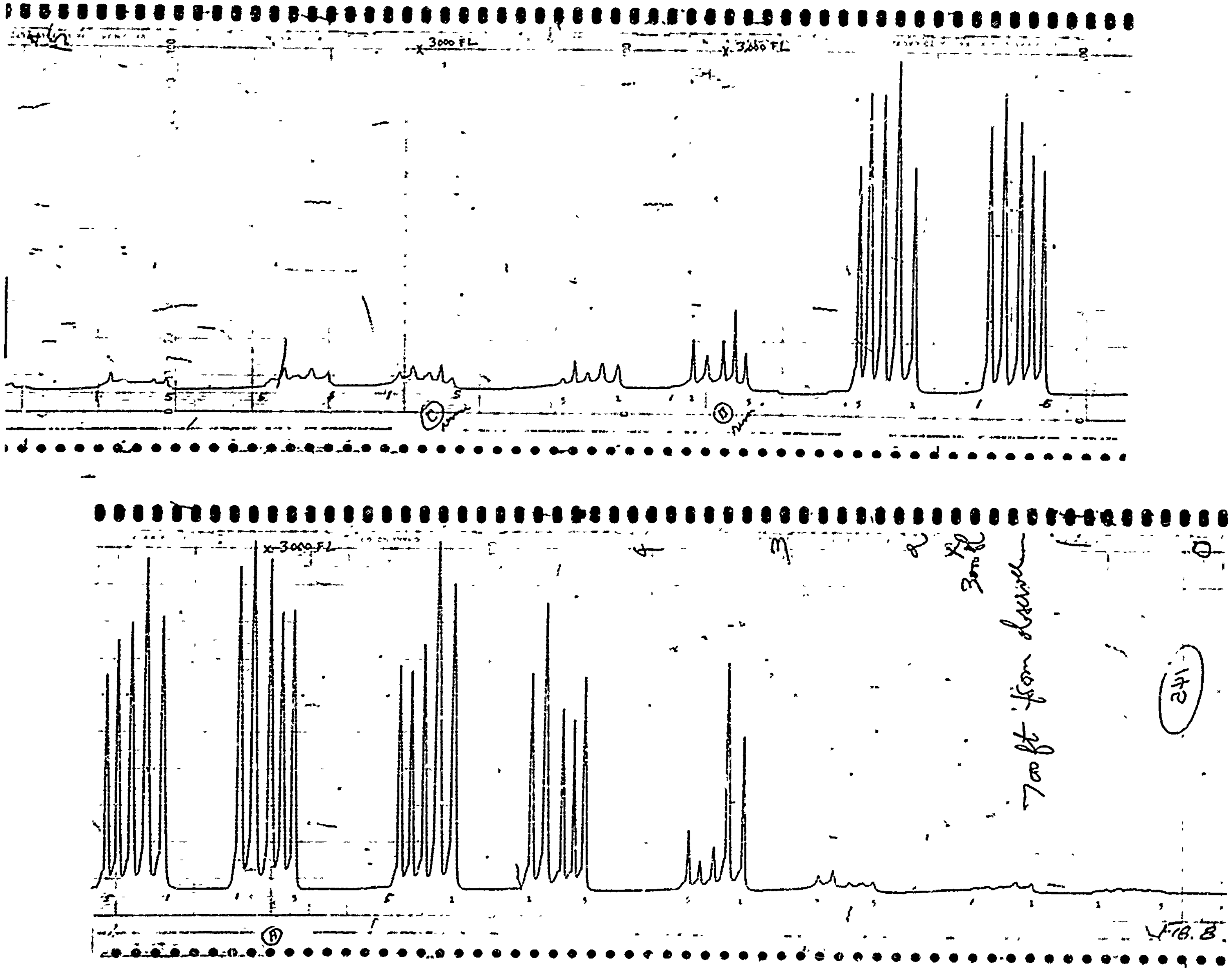
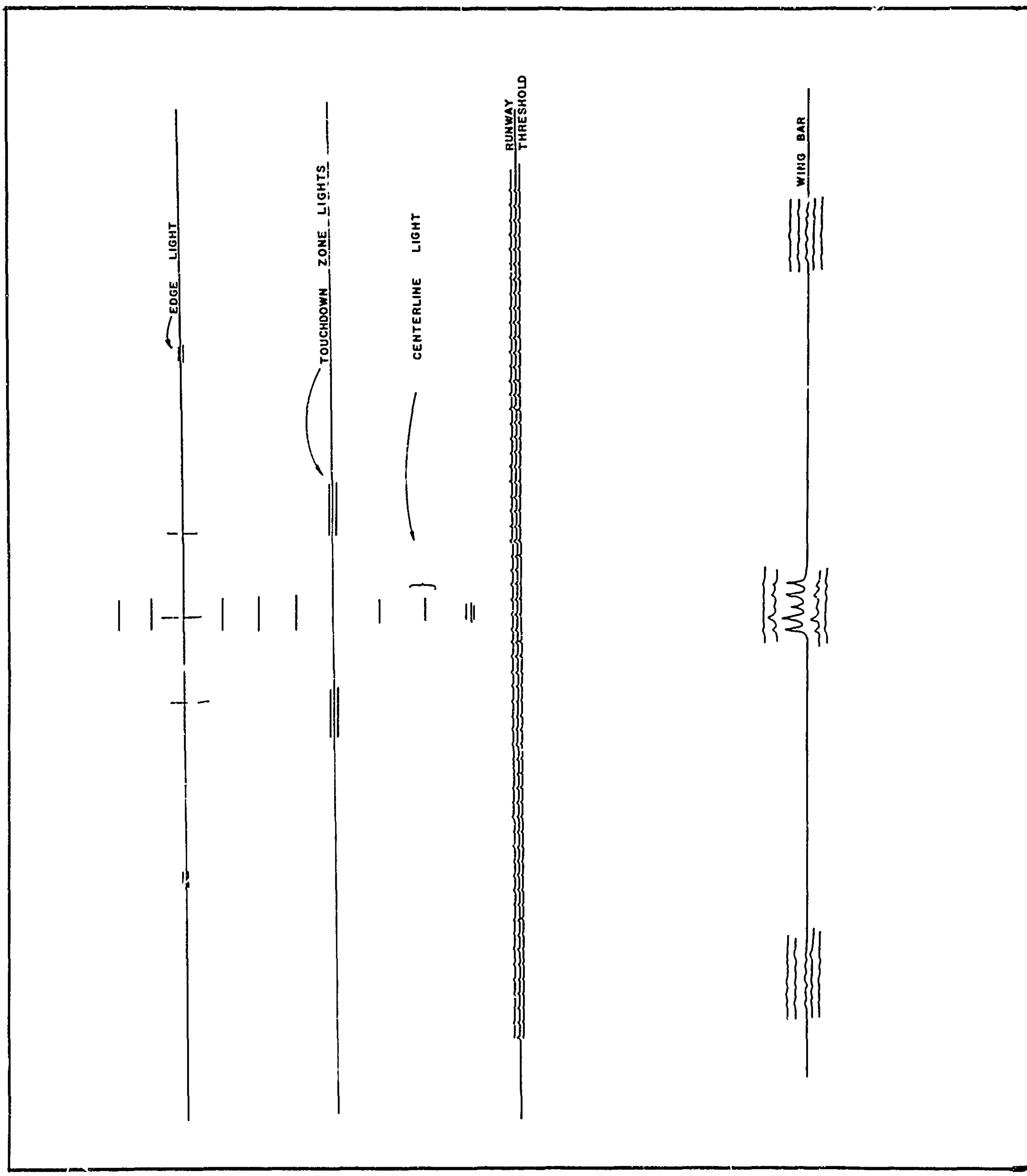


Fig. 8. Typical continuous-scan luminance recording for one approach-light barrette.


EDGE LIGHT
TOUCHDOWN ZONE LIGHTS
CENTERLINE LIGHT
RUNWAY
THRESHOLD
WING BAR

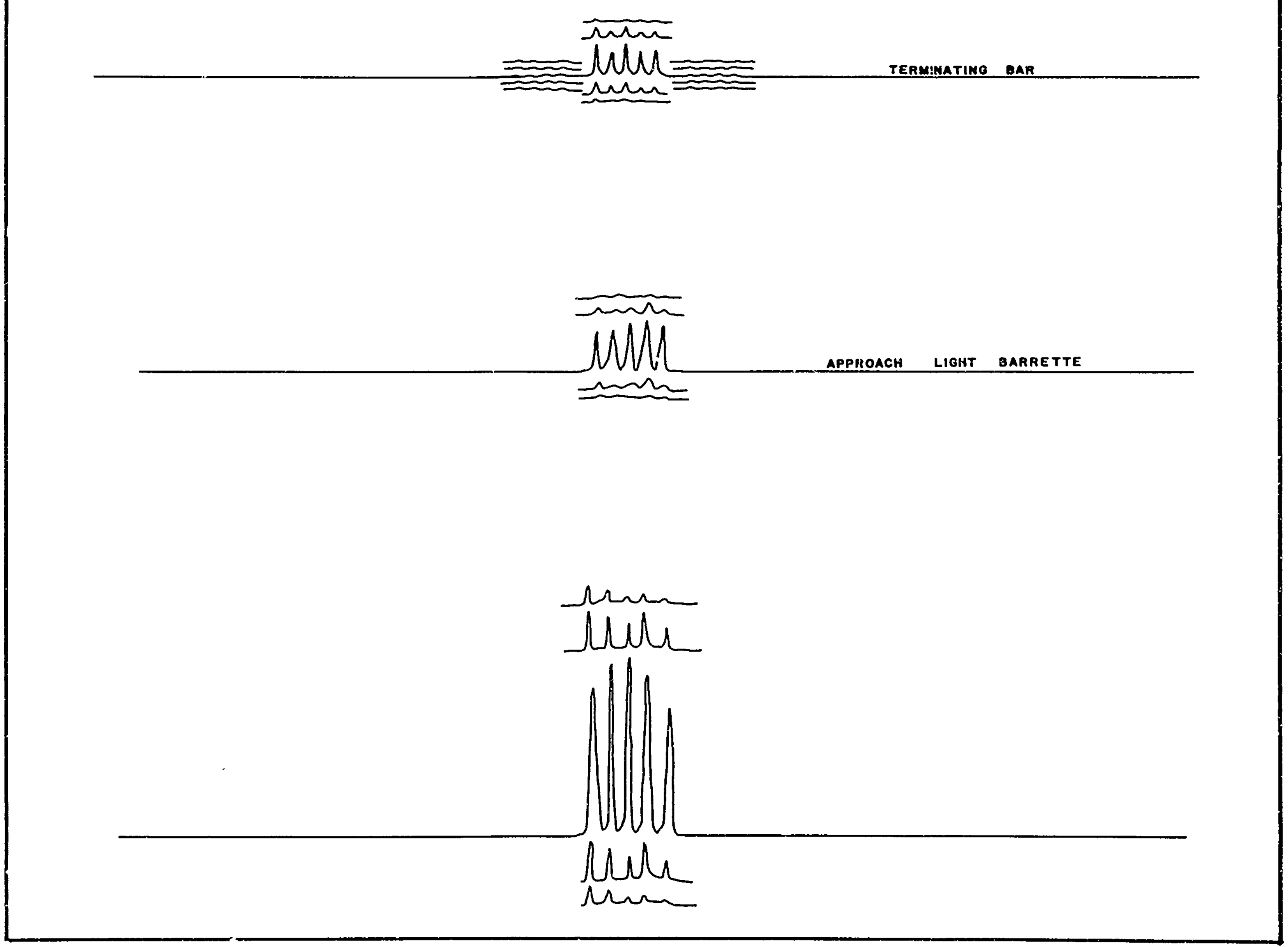
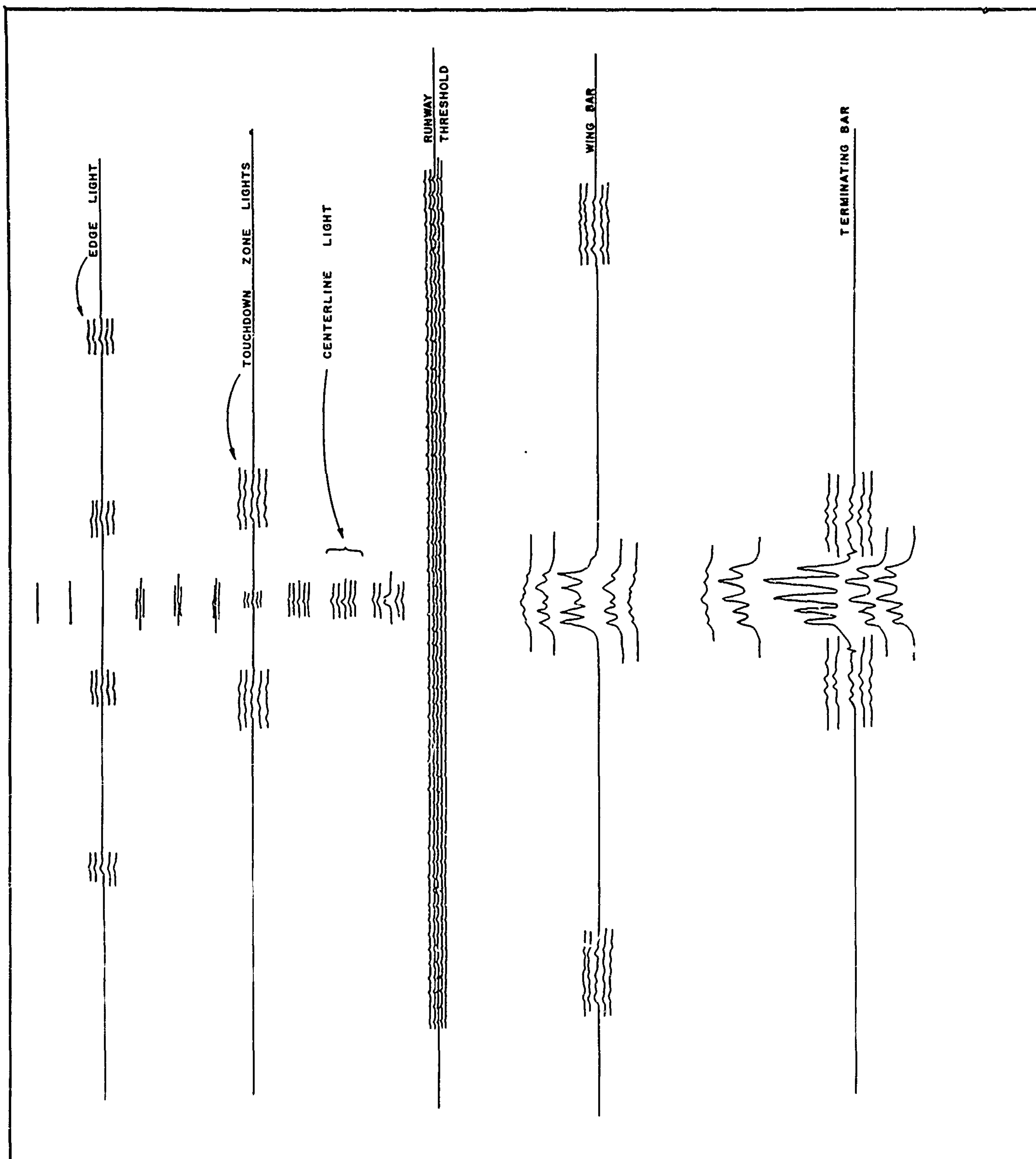


Fig. 9. Daytime luminance map of runway lighting system viewed from 1000 ft before runway threshold in 1200-ft visual range.


EDGE LIGHT
TOUCHDOWN ZONE LIGHTS
CENTERLINE LIGHT
RUNWAY THRESHOLD
WING BAR
TERMINATING BAR

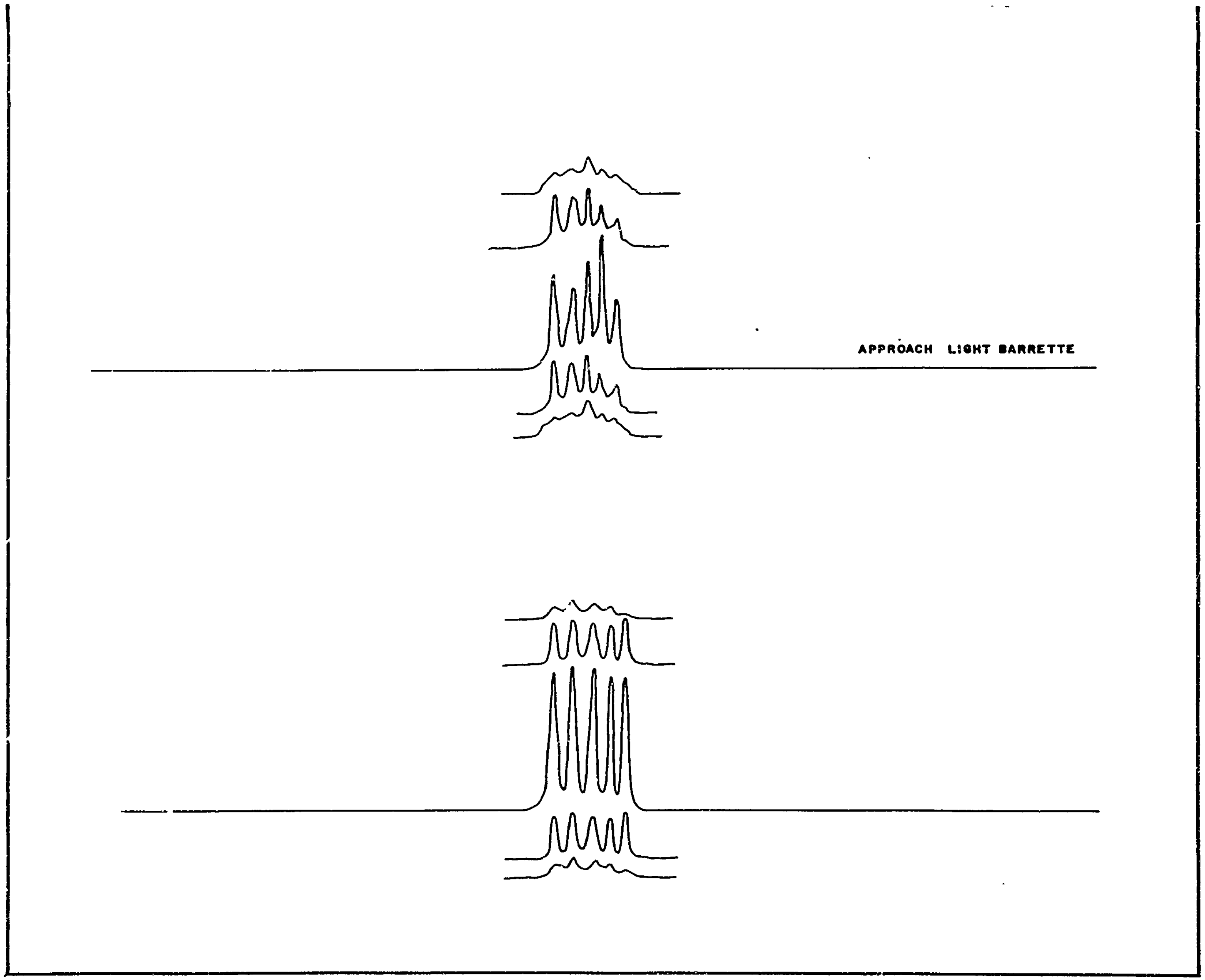


Fig. 10. Nighttime luminance map of runway lighting system viewed from 1000 ft before runway threshold in 1200-ft visual range.

To supplement the photometric data, black and white photographs of the runway lighting system were taken under each of the test conditions and from the same glide path positions used for the luminance measurements. The camera, in all cases, was set up inside the cockpit cabin at the pilot eye-level and a cockpit cutoff angle of 15° used.

TEST RESULTS AND DISCUSSION

To present the photometric data in terms of visibility, a quantity known as "photometer detection contrast" was used. This quantity is derived in the following manner: The increment in light flux at the pilot's eye produced by a light source on the runway is represented by the term ΔB, which is equal to the difference between the peak average luminance and the average luminance approximately one aperture-diameter away from the peak. To account for the effect of background brightness on the pilot's visual sensitivity, ΔB is compared with the average luminance in the general area surrounding the light source. This comparison takes the form of a ratio called the photometer detection contrast, expressed symbolically as follows:

$$C_d = \frac{\Delta B}{B_T} = \frac{B_s - B_o}{B_T}$$

Where C_d = photometer detection contrast

B_s = peak average luminance of the lights within the specified aperture area.

B_o = average luminance one aperture-diameter away from peak average brightness.

B_T = average luminance reading for transverse section scanned exclusive of light peaks.

Using the above relationship, the value of C_d was calculated for each of the single-scan luminance curves of Figs. 3 through 7. Furthermore, in order to relate the photometer detection contrast to the visual contrast threshold, values of C_d for a section of centerline lights were calculated from the continuous-scan luminance recordings and these values were then plotted as a function of distance as shown in Figs. 11 and 12.

It can be seen from the data that the value of C_d most frequently obtained for the farthest perceptible light source under all conditions is .02. This value was therefore considered as corresponding to the threshold visibility. For practical purposes, however, the threshold value must be increased by some factor appropriate to the conditions of observation. Consequently, on the basis of work by Blackwell and others,* a multiplication factor of 3 was chosen, giving a photometer detection contrast of .06 as the minimum value to be used in establishing the visibility of the runway lights.

The factor of 3 was arrived at as follows: Blackwell uses a factor of 2 to increase the certainty of detection from 50% (corresponding to visibility threshold) to 99%. Beyond that point, Blackwell finally arrives at field factors ranging from 10 to 20 as practical values for various conditions and work tasks. In the present application, however, pilots are familiar with the runway lighting patterns and, unlike Blackwell's subjects, know just what to expect. Furthermore, the pilots are relatively attentive and concentrating on seeing the lights to obtain guidance. Also, the runway lights are not isolated sources but part of a continuous pattern. With these considerations in mind, it was judged that a 50% increase in the basic certainty factor of 2 would result in a suitable field factor for use in this case.

*IES Lighting Handbook, Third Ed., p. 2-33 ff.

From the data in Figs. 3 through 7 and the curves of Figs. 11 and 12, the distances from the observation points to the light elements corresponding to a C_d value of .06 were obtained by interpolation for each component of the lighting system under all test conditions. These figures, shown in Tables 1 and 2, thus represent the horizontal distances to the farthest lights in the system that would be seen by pilots under each of the test conditions, based on the assumption that the photometer detection contrast of .06 used here as a minimum is valid.

It is recognized, of course, that the figure of .06 is only an approximation and that a good deal of additional work must be done to establish the relationship between photometer detection contrast and subjective visibility of lights under the conditions prevailing in these studies. Nevertheless, the assumption made here serves to illustrate the manner in which photometric data can be used in evaluating the effectiveness of the lighting system under various conditions of visual range and background brightness.

Thus, any appropriate value of C_d may be used as a minimum and applied to the photometric data to obtain the corresponding maximum visibility distances. The deterioration of the lighting system's effectiveness with decreasing visual range can then be noted in terms of these distances and an evaluation made on this basis.

Moreover, the auto-scan technique previously described, with the use of photometer apertures of 2', 3', 4', 5' and 6', provides a highly efficient method of collecting the photometric data for the complete runway lighting system.*

*The additional 3' and 5' apertures will be available for future investigations.

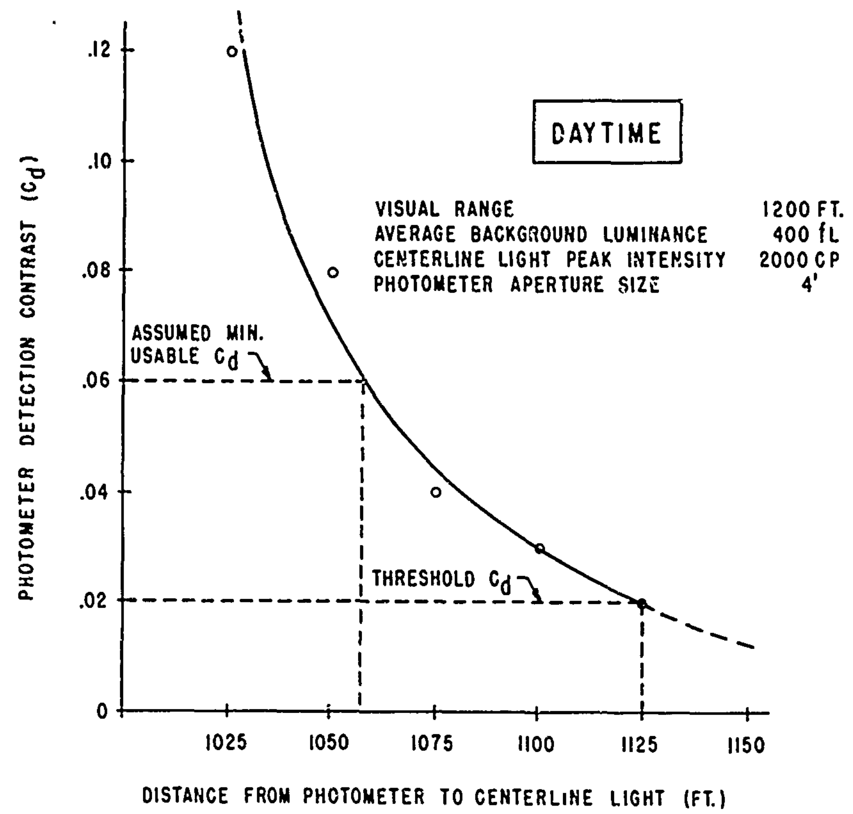


Fig. 11. Photometer detection contrast of centerline lights in daytime as a function of observation distance.

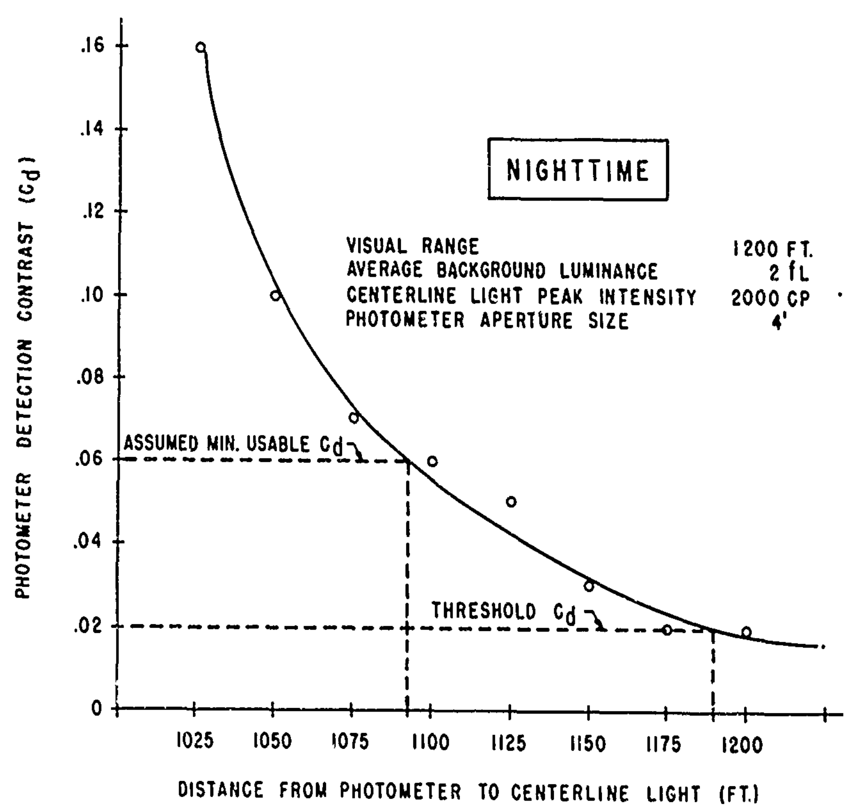


Fig. 12. Photometer detection contrast of centerline lights at night as a function of observation distance.

TABLE 1 - VISIBILITY OF RUNWAY LIGHTING SYSTEM COMPONENTS IN DAYTIME FOGS[a]

Observation Point	Visual Range (ft)	Approach Lights Distance[b] (ft)	Approach Lights No.[c]	Threshold Lights	Centerline Lights Distance[b] (ft)	Centerline Lights No.[c]	Touchdown Zone Lights Distance[b] (ft)	Touchdown Zone Lights No.[d]	Edge Lights Distance[b] (ft)	Edge Lights No.[d]
2000 ft before runway threshold	1600	1500	10	n.v.[e]	n.v.		n.v.		n.v.	
	1200	1100	6	n.v.	n.v.		n.v.		n.v.	
	800	700	2	n.v.	n.v.		n.v.		n.v.	
1500 ft before runway threshold	1600	1400[f]	10	n.v.	n.v.		n.v.		n.v.	
	1200	1100	7	n.v.	n.v.		n.v.		n.v.	
	800	700	3	n.v.	n.v.		n.v.		n.v.	
1000 ft before runway threshold	1600	900[f]	6	visible	1425	17	1400	4	1600	3
	1200	900[f]	6	visible	n.v.		n.v.		n.v.	
	800	700	4	n.v.	n.v.		n.v.		n.v.	
500 ft before runway threshold	1600	400[f]	2	visible	1475	39	1400	9	1500	5
	1200	400[f]	2	visible	1050	22	1000	5	1100	3
	800	400[f]	2	visible	675	7	600	1	700	1
At runway threshold	1600	n.v.		n.v.	1375	48	1300	12	1400	7
	1200	n.v.		n.v.	1000	33	1000	9	1000	5
	800	n.v.		n.v.	650	19	600	5	600	3

Notes

a. Based on a minimum usable photometer detection contrast (C_d) of .06.
b. Horizontal distance from observation point to furthest visible light element.
c. Number of light elements visible (assuming a cockpit cutoff angle of 15°).
d. Number of light elements visible on one side of centerline only (assuming a cockpit cutoff angle of 15°).
e. Not visible.
f. Distance to last approach light barrette before runway threshold.

TABLE 2 - VISIBILITY OF RUNWAY LIGHTING SYSTEM COMPONENTS IN NIGHTTIME FOGS[a]

Observation Point	Visual Range (ft)	Approach Lights Distance[b] (ft)	Approach Lights No.[c]	Threshold Lights	Centerline Lights Distance[b] (ft)	Centerline Lights No.[c]	Touchdown Zone Lights Distance[b] (ft)	Touchdown Zone Lights No.[d]	Edge Lights Distance[b] (ft)	Edge Lights No.[d]
2000 ft before runway threshold	1600	1500	10	n.v.[e]	n.v.		n.v.		n.v.	
	1200	1100	6	n.v.	n.v.		n.v.		n.v.	
	800	800	3	n.v.	n.v.		n.v.		n.v.	
1500 ft before runway threshold	1600	1400[f]	10	n.v.	n.v.		n.v.		n.v.	
	1200	1100	7	n.v.	n.v.		n.v.		n.v.	
	800	700	3	n.v.	n.v.		n.v.		n.v.	
1000 ft before runway threshold	1600	900[f]	6	visible	1500	20	1400	4	1400	2
	1200	900[f]	6	n.v.	n.v.		1100	1	1200	1
	800	700	4	n.v.	n.v.		n.v.		n.v.	
500 ft before runway threshold	1600	400[f]	2	visible	1400	38	1400	9	1500	5
	1200	400[f]	2	visible	1000	20	1000	5	1100	3
	800	400[f]	2	visible	700	8	700	2	700	1
At runway threshold	1600	n.v.		n.v.	1550	55	1400	13	1400	7
	1200	n.v.		n.v.	1025	34	1000	9	1000	5
	800	n.v.		n.v.	725	22	700	6	600	3

Notes

a. Based on a minimum usable photometer detection contrast (C_d) of .06.
b. Horizontal distance from observation point to furthest visible light element.
c. Number of light elements visible (assuming a cockpit cutoff angle of 15°).
d. Number of light elements visible on one side of centerline only (assuming a cockpit cutoff angle of 15°).
e. Not visible.
f. Distance to last appraoch light barrette before runway threshold.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The results of this investigation demonstrate that the photometric method herein described may be quite useful for evaluating the effectiveness of a runway lighting system in various visibility conditions if the necessary correlations between subjective and photometer detection contrasts can be established. The photometric method has the following advantages:

1. It provides a means of collecting test data that is much more efficient and economical than the use of pilot observers.

2. The data thus collected, being objective in nature, does not display vagaries often encountered in subjective determinations.

3. The photometric data, once obtained, remain useful for making runway lighting evaluations even though subsequent work requires changes in the criteria for effectiveness.

Although the data obtained in these tests reflect the need for further refinement of the photometric techniques employed, some general indications can be discerned. Thus, the figures in Tables 1 and 2 show that the horizontal distances to the farthest lights in the system that would be seen in a given visual range are somewhat less than the distance corresponding to the visual range. These distances, moreover, are generally closer to the corresponding visual range distance in the case of the higher intensity components of the system (approach and edge lights, daytime setting) than for the lower-intensity components (centerline and touchdown zone lights). It also appears from the data that as the visual range decreases, the guidance effectiveness of the various components of the lighting system is not degraded at the same rate.

Recommendations

On the basis of the work reported here, it is recommended that:

a) Extensive subjective visibility tests be performed in daytime and nighttime fog conditions to better establish the correlation between the photometer detection contrast and visual perception of lights under these conditions.

b) Future reduced visibility evaluations of runway lighting systems in the Fog Chamber employ the photometric method described in addition to pilot observation runs.